FINAL REPORT

Title: Effects of pre-fire forest and fuels treatment on post-fire forest composition, forest resilience, and occupancy of an endangered squirrel

JFSP PROJECT ID: 19-1-01-52

September 2021

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Keywords
fuel treatment, silviculture, wildfire, occupancy, adaptive management

Acknowledgements

We would like to thank our collaborators at the USDA Forest Service Coronado Forest District and the US Fish and Wildlife Service for offering their time and knowledge to help us build this project. We would also like to thank our volunteers and technicians for taking the time to help us collect data. Finally, we would like to thank the Joint Fire Science Program for funding this research through their Graduate Research Innovation Grant program.

Abstract

Wildfires are a natural occurrence which can be beneficial to forested ecosystems. With current threats such as climate change, bark beetle damage, invasive species, and fire suppression, the beneficial role of wildfire has been altered in many ecosystems. Current high intensity fires have impacted ecosystem resilience and, in some cases, contributed to permanent shifts in ecosystem state. These shifts have severe implications for wildlife and overall ecosystem function. Forest treatments such as fuel reduction and overstory silviculture treatments have been used for decades to improve overall forest health and reduce the susceptibility of forests to severe wildfire. Although these treatments are commonly used, assessments of their effectiveness are uncommon. With rapidly changing environmental conditions influencing fire behavior, it is essential to establish iterative, learning-based methods to ensure that treatments implemented now and at any point in the future will be effective in producing desired management outcomes. We used a naturally occurring fire to assess the effectiveness of treatments associated with the Pinaleño Ecosystem Restoration Plan in improving forest resilience and conserving habitat for the federally endangered Mount Graham red squirrel (*Tamiasciurus fremonti grahamensis*: MGRS) in southeastern Arizona, USA. Both fuel reduction and mechanical silviculture treatments were implemented as part of the PERP prior to the Frye Fire in 2017. We used a combination of fine-scale forest vegetation assessments and passive and active remotely sensed data to assess pre- and post-fire vegetation and microclimate conditions as well as habitat suitability for MGRS among three treatment categories (fuel, silviculture, and control/untreated) within the burn perimeter of the Frye Fire. Both fuel and silviculture treatments were associated with increased coarse woody debris, decreased prevalence of recent snags, and increased understory herbaceous diversity. Silviculture treatments were associated with greater post-fire seedling establishment, however, the majority of seedlings observed were aspen. Additionally, overall average summer soil temperatures were higher in silviculture treatments post-fire as compared to both fuel and control units, which could be disadvantageous for conifer reestablishment. Fuel treatments reduced overall burn severity, reduced the probability of immediate post-fire tree mortality, and increased forest resilience whereas silviculture treatments were associated with overall higher burn severity and were not significantly different from control units for probability of tree mortality or forest resilience. Additionally, fuel treatments were associated with higher probability of occupancy of MGRS post-fire as compared to control units, whereas silviculture treatments were associated with lower probability of occupancy of MGRS. Slash disposal within silviculture treatments was incomplete prior to the Frye Fire, suggesting remaining slash from either mastication, hand piling, or lop and scatter methods may have contributed to the overall poor effectiveness of silviculture treatments. We recommend continued use of fuel treatments for improving overall forest health, resilience, and for conserving habitat for MGRS. We do not recommend continued use of silviculture treatments within or nearby critical habitat for MGRS unless slash disposal methods are improved.

Objectives

The Joint Fire Science Program (JFSP) has stated a continued need for landscape-level studies that evaluate the effectiveness of forest and fuels treatments to reduce fire severity and minimize degradation of important natural resources. Having this knowledge is critical to execute management plans which can be flexible in the face of changing disturbance regimes. To address this need, the objective of our study was to assess the efficacy of forest fuel reduction and silviculture treatments to reduce negative impacts associated a large-scale wildfire on high elevation mixed conifer forest in southeastern Arizona, USA. Specifically, we assessed burn severity, post-fire fine-scale forest composition and structure, post-fire microclimate conditions, tree mortality, forest resilience, and probability of occupancy for the federally endangered Mount Graham red squirrel (*Tamiasciurus fremonti grahamensis*: MGRS). We analyzed both acute impacts 3 months post-fire and long-term impacts up to four years following the fire using a combination of field assessments and remotely sensed data. We used our findings to assess the effectiveness of current treatments associated with the Pinaleño Ecosystem Restoration Plan (PERP) and will also be using results to develop an iterative structured decision-making management framework to facilitate active learning about management outcomes and support current and future management objectives.

Objective 1: Did silviculture and fuel reduction treatments better maintain microclimate conditions and fine-scale forest conditions desired by the PERP as compared to areas which did not receive treatments? This objective was met by establishing 57 forest inventory plots stratified among our three treatment categories (fuel, silviculture, and untreated) three years post-fire. Answering this question allowed us to determine if forest treatments adequately retained fine-scale forest features that are both valuable for habitat for MGRS as designated in the PERP and would signal potential forest recovery to pre-fire condition.

Objective 2: Was burn severity and immediate post-fire tree mortality reduced within silviculture and fuel reduction treatments as compared to forested units which did not receive treatments? We met this objective by using a combination of active and passive remote sensing technology and assessing loss of individual trees three months post-fire. Answering this question helped us determine whether treatments were less susceptible to high severity fire as compared to untreated areas.

Objective 3: Was rate of recovery of forests which received either fuel reduction or silviculture treatments higher than areas that were not treated? We also used a combination of active and passive remote sensing data to meet this objective. We followed trends in NDVI of individual trees three months and one to three years following the fire. This objective allowed us to detect differences in forest resilience among treatment categories.

Objective 4: Did silviculture and fuel reduction treatments support continued occupancy of MGRS post-fire more than areas which did not receive treatments? We used methodology published in a prior study of MGRS occupancy (Hatten 2014) to determine probability of occupancy pre-fire and one to four years following the fire. We compared rate of change of occupancy among our three treatment categories to determine if treatments were effective in retaining MGRS habitat through fire.

Background

Climate change, human activity, bark beetle damage, fire suppression, and invasive species have changed the behavior of wildfire on western landscapes (Hudak et al. 2011). High intensity fires fueled by these threats have the capacity to alter entire landscapes and potentially alter the trajectory of vegetation recovery post-fire (Koprowski et al. 2005; Johnstone et al. 2016). It is increasingly recognized that traditional management practices are no longer sufficient in addressing these rapid changes (Folke et al. 2004; Schwartz et al. 2012). Adaptive management is one strategy currently used to accommodate uncertainty associated with changing disturbance regimes and, consequentially, changing forests (Allan & Curtis 2005; Stein et al. 2013). Although several published examples of adaptive management exist, many of these examples still lack empirical evidence to suggest they have implemented any monitoring or assessment to ascertain that current management practices are effective in either reducing the susceptibility of forests to high intensity fire or promoting resilience in the face of change (Mawdsley et al. 2009; Nagel et al. 2017). To truly be considered adaptive, management strategies must incorporate an iterative process which allows users to learn from potential shortcomings and adjust actions moving forward (Mawdsley et al., 2009; Magness et al., 2012; Mattsson et al., 2018).

In the Madrean Sky Islands of southern Arizona, USA, drought and bark beetle damage have left island forests vulnerable to severe fires. In 2010, the PERP (US Forest Service 2010) received federal clearance to initiate forest treatments intended to promote forest resilience and increase habitat quality for sensitive wildlife species inhabiting the mountain range, including the federally endangered Mount Graham red squirrel (*Tamiasciurus fremonti grahamensis*: MGRS) and the threatened Mexican spotted owl (*Strix occidentalis lucida*). Prior to 2017, approximately 150 ha of forest received forest treatments within the PERP planned treatment area, including mechanical overstory thinning and understory thinning and prescribed burning. Since the implementation of the PERP, however, there has been no monitoring to assess the effectiveness of the forest treatments in either increasing habitat suitability for sensitive species or increasing forest resilience through large-scale disturbance events.

In 2017, the Frye Fire burned approximately 19,000 ha of mixed conifer forest, much of it within important habitat for MGRS. The fire presented an opportunity, however, to assess whether pre-fire forest treatments altered the outcome and trajectory of vegetation condition either by improving forest stand resilience or by maintaining high quality habitat for MGRS (McGarigal & Cushman 2002).

Methods

Study Site

The Pinaleño Mountains are located in the desert southwest of the United States in a region known as the Madrean Sky Island Complex. The Madrean Sky Island Complex includes a series of high elevation mountain ranges that are isolated from each other by large expanses of desert (Brown & Lowe 1982). At low elevations, the Pinaleños are characterized by desert chaparral, including yucca, perennial grasses, and acacia. At mid-elevations, desert vegetation transitions to mixed deciduous woodland and pine, including several oak species, maple, and Ponderosa pine (*Pinus ponderosa*). Woodlands transition into mixed conifer at the highest elevations, including Engelmann spruce (*Picea engelmannii*), Douglas fir (*Pseudotsuga menziesii)*, and corkbark fir (*Abies lasiocarpa*). The peak, Mount Graham, is the tallest peak in southern Arizona at 3,268 m.

The PERP planned treatment area encompasses approximately 2,300 ha of mixed conifer forests at the highest elevations of the Pinaleños (Fig. 1). Our study took place within this zone in areas that had been treated using either fuel reduction techniques or overstory/silviculture techniques. Control units were designated as areas that had not received any treatment as part of the PERP or for at least ten years prior to the Frye Fire (Agee & Skinner 2005; Keifer et al. 2006; Battaglia et al. 2008; Martinson and Omi 2013). The boundaries of the control units are subunits of the PERP planned for future treatment. We selected subunits based on their designated future prescription to represent controls for both fuel and silviculture treatments.

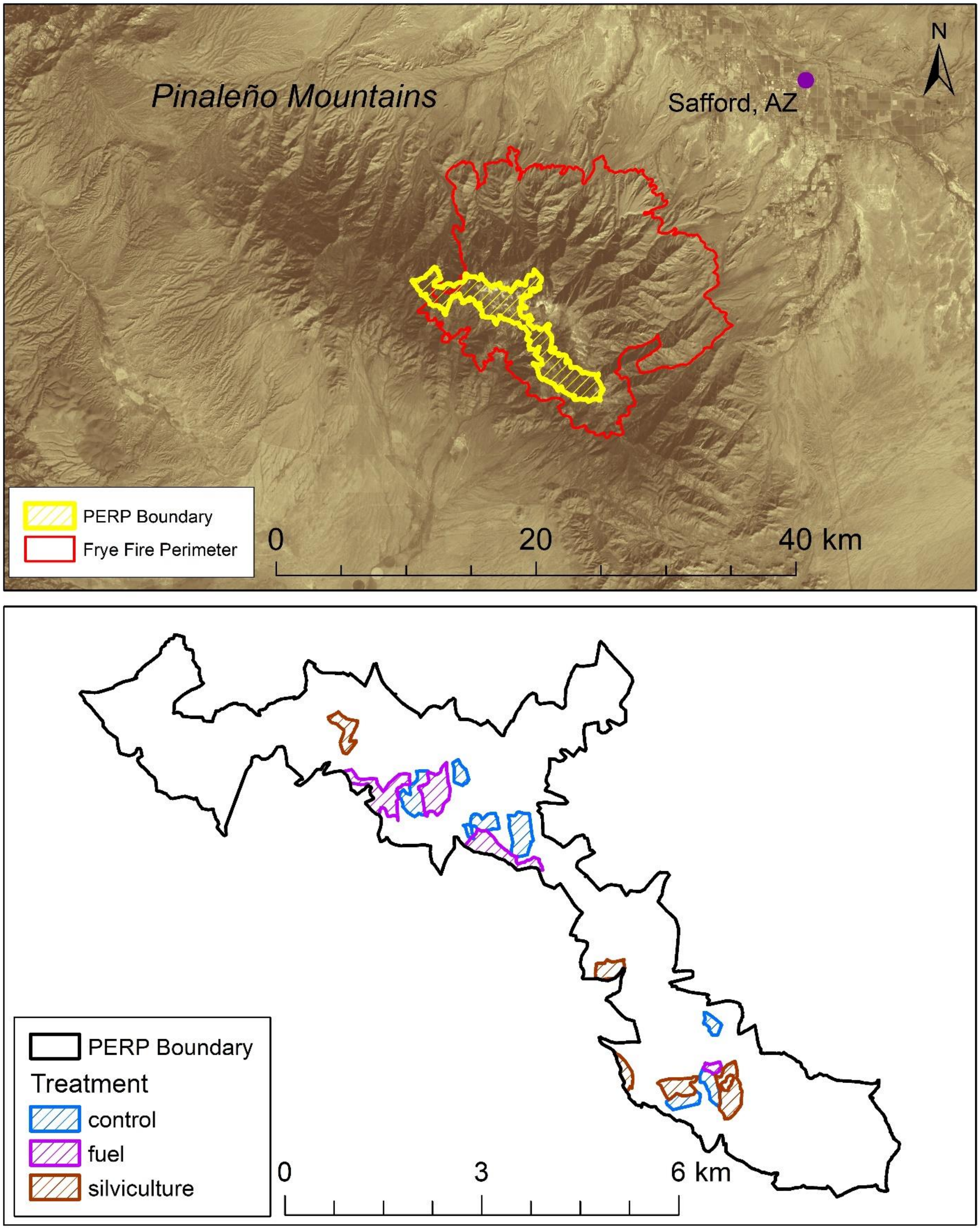

Figure 1: Location of the Pinaleño Ecosystem Restoration Plan treatment area and treatment units sampled in a study of post-fire forest treatment effectiveness in the Pinaleño Mountains, AZ, USA, 2020-2021.

Fine-scale Forest and Microclimate Condition

The PERP highlights several fine-scale forest components known to be important to overall forest health and to habitat for MGRS. These include coarse woody debris, presence of snags, herbaceous vegetation cover, conditions for seedling establishment, and basal area cover of live trees. MGRS habitat is characterized by mature mixed conifer forests which contain features essential for reproduction and survival (Smith & Mannan 1994; Merrick et al. 2007; US Forest Service 2010). Coarse woody debris is an important structural element of MGRS habitat because it is often used by MGRS to create middens and cache cones. Snags are also important features which are commonly used by MGRS for nesting. Soil conditions such as moisture content and temperature influence successful conifer seedling establishment (Singleton et al. 2021) and live tree basal area coverage also has important implications for seedling recruitment and therefore persistence of mixed conifer forests important for MGRS and overall forest health.

We used a stratified random sampling scheme to place 57 plots within low-, moderate-, and high-burn severity classes as indicated by the post-fire differenced Normalized Burn Ratio (dNBR). We controlled for confounding topographic features by placing all plots on southwest facing slopes with no more than a 15% grade. All plots were at least 60 m apart and 60 m from the boundary of the treatment zone. We used a similar forest sampling design as Hudak et al. (2011) and Dodge et al. (2019) to measure fine-scale forest composition, structure, and microclimate conditions (Fig. 2). Fine-scale forest composition and structure features included percent cover of coarse woody debris, basal area coverage of snags, percent cover of understory plants and abiotic features such as bare ground, seedling and sapling density, and live tree basal area coverage. Coarse woody debris was measured along three 10-m long transects radiating from plot center using guidance from Woodall (2010). Basal area coverage of snags was measured within an 11.3 m radius (0.04 ha) from plot center and snags were classified as either fresh (mostly intact canopy and majority of bark present), moderate (still maintaining structural integrity but with larger portions of bark and canopy missing), or decayed (structural integrity compromised). Understory vegetation and abiotic ground surface features were measured within five 1-m^2 quadrats at plot center and at each of the four cardinal directions within the plot. We recorded both vegetation species composition and functional groups, bare soil cover, rock cover, and fine woody debris cover. We additionally measured the diameter at breast height (DBH) of all live trees $\geq$ 10 cm DBH within 11.3 m of plot center and identified the species of each tree measured. We counted all tree seedling and saplings within 5.3 m of plot center.

Microclimate conditions (soil temperature and soil moisture) were collected from plot establishment (June-July 2020) through May of 2021. HOBO MX2201 soil temperature sensor loggers (Onset Computer Corporation, Bourne, MA, USA) were buried 5-7 cm below ground at plot center and were used to record soil temperature on a pre-programed schedule every eight hours. Soil moisture content (mV) was manually measured weekly during snow-off periods using a SM150T soil moisture probe (Delta-T Devices Ltd, Cambridge, England).

We used a multinomial logistic regression model to determine if fine-scale vegetation and abiotic features (including microclimate conditions) could be used to described differences among treatment categories (control, fuel, and silviculture). We used Akaike's information criteria adjusted for small sample size to rank models and McFadden's pseudo-R^2 to assess model fit. We also used leave-one-out cross validation to see if predictors in our top model adequately predicted whether a plot occurred within a control, fuel, and silviculture treatment.

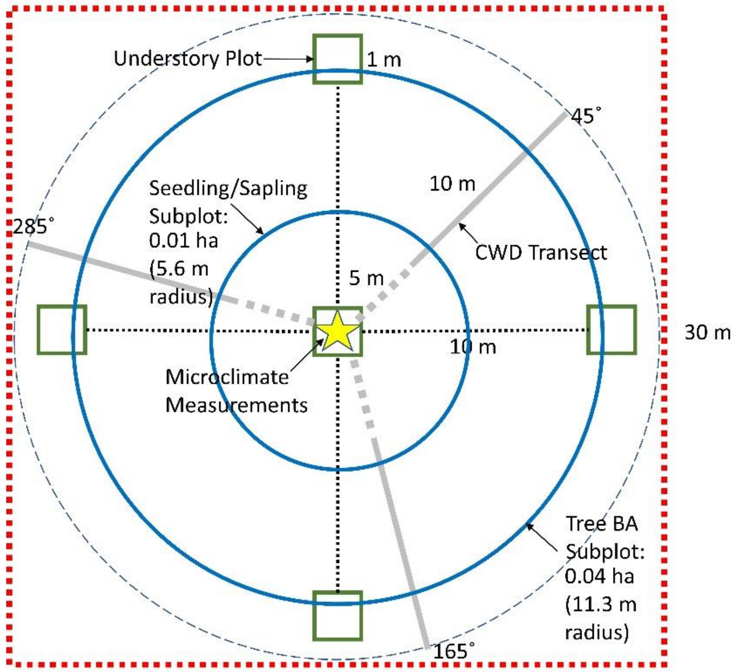

Figure 2: Plot sampling design used to measure fine-scale vegetation composition, structure, and microclimate conditions in a study of post-fire forest treatment effectiveness in the Pinaleño Mountains, southeastern AZ, USA, 2020-2021.

Tree Mortality and Stand Resilience

Satellite-derived spatial metrics and discrete return light detection and ranging (lidar) data were used to test the effectiveness of forest treatments to reduce immediate fire-induced tree mortality and promote forest resilience. To identify individual trees, we segmented individual tree canopies from a lidar dataset collected pre-fire in 2008 (Dalponte and Coomes 2016). To reduce the likelihood of including trees that died prior to 2017, we used 3-m resolution PlanetScope imagery to calculate vegetation greenness (NDVI) within individual tree canopies generated using the lidar data. If tree canopies had an average NDVI of less than 0.42, we excluded them from analysis. We measured immediate post-fire tree mortality by setting NDVI and percent change NDVI thresholds for individual trees. If trees had, 1) an NDVI <0.4 three months post-fire (Brodrick & Asner 2017), 2) an average percent change in NDVI < 0 for three years following the fire AND 3) an NDVI<0.4 three years following the fire, they were labeled as dead. We used a binomial logistic regression to assess if treatment category affected probability of immediate tree mortality, using treatment type and burn severity as predictors.

Forest resilience was calculated for all remaining trees considered alive three months post-fire. We used a generalized linear model to assess rate of recovery, with burn severity, treatment type, and time since fire as predictors and NDVI as the response.

MGRS Occupancy

We used an existing occupancy analysis developed by Hatten (2014) to assess occupancy and habitat suitability for MGRS pre- and one to four years post-fire. The logistic regression equation used included elevation, aspect, slope, and NDVI as predictors of occupancy (Hatten 2014). This equation was developed using 385 midden sites which were active in 2008 and 2009. The resulting model coefficients were used with 30-m Landsat 8 imagery to predict probability of occupancy on a landscape scale.

Results and Discussion

Fine-scale Forest and Microclimate Condition

Our highest ranking model included seven predictor variables: coarse woody debris, fresh snags, herbaceous diversity, tree seedling count, average summer soil temperature, average spring soil moisture content, and the standard deviation of spring soil moisture content (Table 1). This model had adequate model fit (McFadden's pseudo-R^2=0.51) and strong predictive ability (LOOCV accuracy= 0.75, 95% CI: 0.6224-0.8587; LOOCV Kappa=0.6306).

Table 1: Best fitting model describing abiotic and biotic conditions used to classify three different forest treatment scenarios (control/untreated, fuel, and silviculture) in the Pinaleño Mountains of southeastern Arizona three years following the 2017 Frye Fire.

	Fuel					Silviculture				
	Coefficient	SE	95% LL	95% UL	P-Value	Coefficient	SE	95% LL	95% UL	P-Value
Intercept	1.50	0.80	-0.07	3.06	0.06	0.60	0.89	-1.15	2.36	0.50
Coarse Woody Debris	1.99	0.78	0.46	3.51	0.01	1.87	0.93	0.05	3.68	0.04
Fresh Snags	-2.24	0.94	-4.09	-0.39	0.02	-3.64	1.11	-5.80	-1.47	0.00
Herbaceous Diversity	1.74	0.78	0.22	3.27	0.03	2.41	0.92	0.61	4.20	0.01
Seedling Count	1.00	0.87	-0.71	2.72	0.25	2.59	1.09	0.45	4.73	0.02
AVG Summer Soil Temp	1.31	0.78	-0.22	2.84	0.09	3.11	1.01	1.13	5.08	0.00
SD Spring Soil Moisture	-2.21	0.87	-3.92	-0.49	0.01	-2.20	1.07	-4.29	-0.11	0.04

Both fuel and silviculture plots were associated with higher percent cover of coarse woody debris (CWD: β: 1.99, p<0.05; β: β: 1.87, p<0.05). These are important components of MGRS habitat, although the cause of higher CWD cover may be different between fuel and silviculture treatments (i.e. differences in burn severity and resulting tree canopy loss vs. pre-existing CWD before the Frye Fire).

Fresh snags were also less prevalent in fuel and silviculture plots as compared to control plots (β: -2.24, $p<0.05$, β: -3.64, $p<0.01$, respectively). Snags are a natural component of mature and old growth forests and are frequently utilized by MGRS for nesting (Merrick et al. 2007). Although fresh snags were less prevalent, there was no difference among treated and untreated units for presence of older snags, which could also be used by MGRS.

Silviculture plots were also associated with a higher tree seedling percent cover and average high summer soil temperature (β: 2.59, $p<0.05$; β: 3.11, $p<0.01$, respectively). Additionally, spring soil moisture content in fuel and silviculture plots was less variable than control plots (β: -2.21, $p<0.05$, β: -2.2, $p<0.05$, respectively). It is important to note, however, that most seedlings were aspen and that very few conifer seedlings were found throughout the study area. Aspen are known to proliferate following fire (Elliott & Baker 2004; Kreider & Yokom 2021). Dependent on future climate and soil conditions, this could result in either a temporary or permanent transition from conifer to aspen-dominated forest stands. Higher soil temperatures associated with silviculture treatments may also negatively impact conifer recruitment (Stephens et al. 2012; McLauchlan et al. 2014). Alternatively, higher soil temperatures resulting from increased exposure of soil to sunlight can increase herbaceous cover and diversity Higher herbaceous diversity was associated with both fuel and silviculture treatments (β: 1.74, $p<0.05$; β: 2.41, $p<0.05$, respectively).

Tree Mortality and Stand Resilience

Change in NDVI was negative for all treatment categories three months post-fire (unburned/low severity: -0.092 ± 0.070 SD; moderate/high severity: -0.248 ± 0.080; Fig. 3). Overall, fuel units experienced significantly lower burn severity as compared to control units (β: -0.804, $p<0.001$). In contrast, silviculture units experienced significantly higher burn severity as compared to control units (β: 0.306, $p<0.001$). This result is likely due to the presence of slash remaining in the understory pre-fire in silviculture treatments. Silviculture treatments received a variety of overstory thinning prescriptions but differed in how slash was disposed of. Disposal methods included chipping, hand piling, and scattering. These are common methods, however, planned slash removal from sites was incomplete pre-fire. Furthermore, slash that was chipped and/or scattered following mastication and lop-and-scatter prescriptions was thick in some areas of the treatment units (Jena Trejo, USFS Forester, personal communication). It is likely that the accumulation of woody debris in the understory contributed to higher burn severity within silviculture units (Dodge et al. 2019).

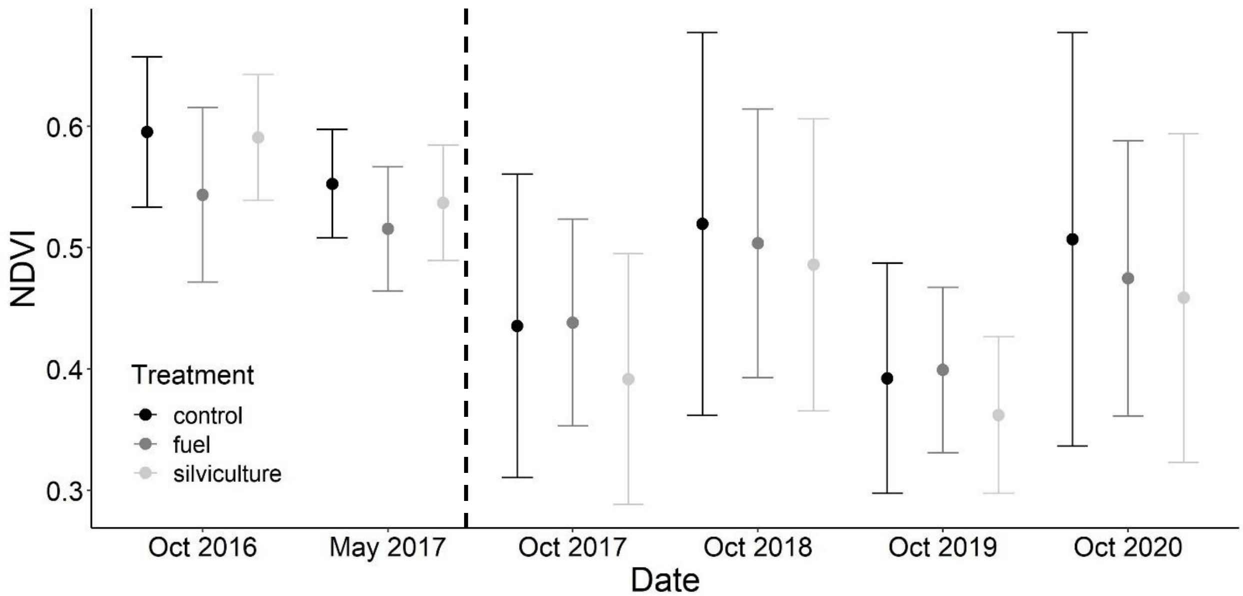

Figure 3: Normalized difference vegetation index (NDVI) for three treatment categories (untreated/control, fuel reduction, and overstory/silviculture treatments) in a study of post-fire forest treatment effectiveness in southeastern AZ, USA, 2020-21. The dashed line denotes occurrence of the Frye Fire in June-July of 2017.

For ease of interpretation and to make sample sizes more equivalent, we chose to consolidate the four burn severity categories into two: unburned/low and moderate/high (Dodge et al. 2019). We found a significant interaction of fuel treatment and burn severity on tree mortality. Transitioning from unburned/low severity to moderate/high severity, fuel units experienced a lower increased probability in tree mortality as compared to control units (β:-2.019, $p<0.01$). This pattern was not found for silviculture units in comparison to control units. Again, because of incomplete disposal of slash, it is likely that an abundance of woody debris in the understory contributed to more severe fire effects. Probability of tree mortality was higher in general among all treatment categories in the moderate/high severity as compared to unburned/low severity (β: 3.922, $p<0.001$).

We found a significant interaction of fuel treatment, time since fire, and burn severity on NDVI, which we used as an estimation of rate of recovery of individual trees post-fire (Fig. 4). Fuel treatments had a slightly higher recovery rate moving from unburned/low to moderate/high severity (β: 0.015, $p<0.05$). There was not significant difference between silviculture and control categories for rate of recovery. Despite a higher rate of recover, both fuel and silviculture categories had lower overall NDVI values as compared to control units (β: -0.070, $p<0.001$; β: -0.045, $p<0.001$, respectively).

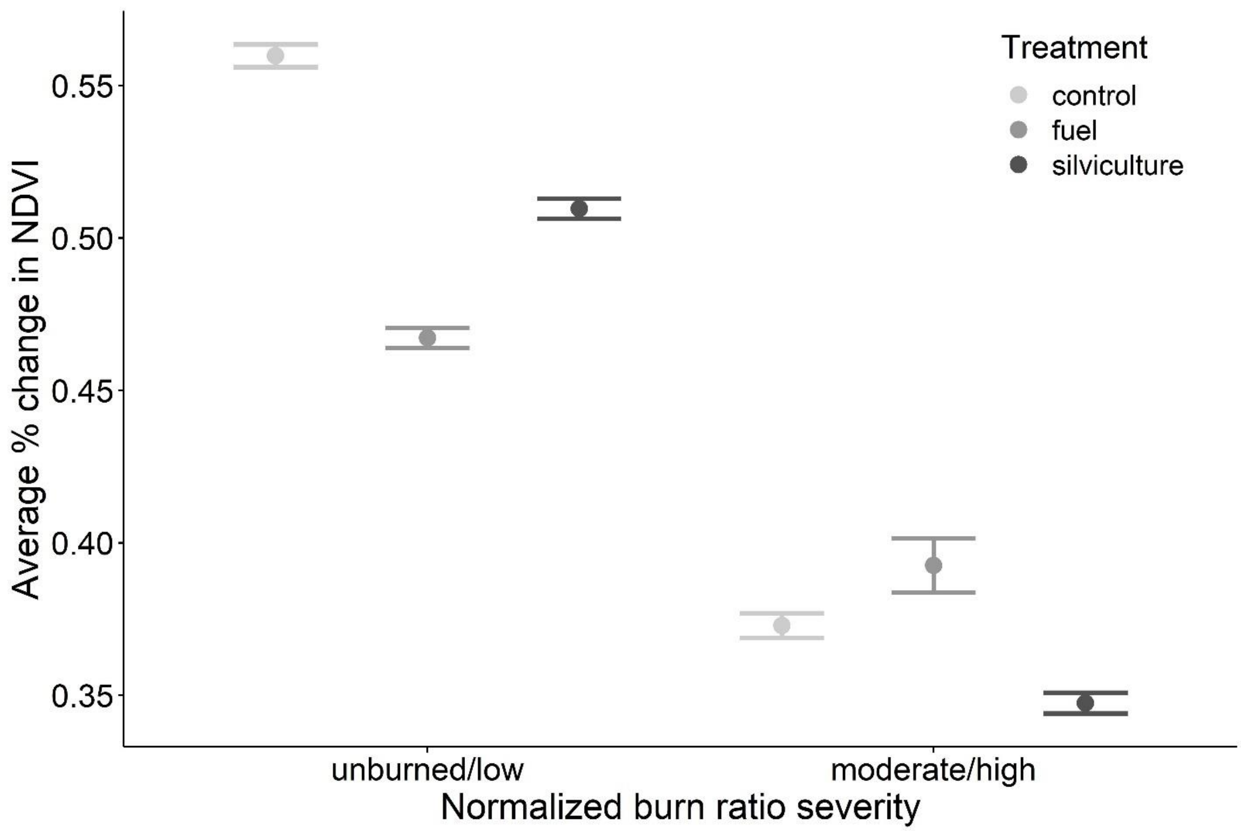

Figure 4: Average percent change in individual tree greenness (NDVI) from October 2017 to October 2020 following the Frye Fire in southeastern AZ, USA. Data are categorized by burn severity and forest treatment category.

MGRS Occupancy

In both 2016 and 2017 pre-fire, probability of occupancy of MGRS was significantly lower in fuel and silviculture units as compared to control units (2016 ex: β: -0.088, $p<0.001$; β: -0.228, $p<0.001$ for fuel and silviculture units, respectively). It is not uncommon that a short-term decline in wildlife habitat quality occurs after a forest treatment (Stephens et al. 2014; Tempel et al. 2014). Although a temporary loss of habitat quality may occur, the objective of performing a forest treatment is to improve forest resilience and resistance to change and ultimately maintain habitat through disturbance (Holbrook et al. 2019). We found mixed support for this. Post-fire probability of occupancy remained significantly lower in silviculture units as compared to control units whereas probability of occupancy became significantly higher for fuel units as compared to control units for all four years following the fire (Fig. 6).

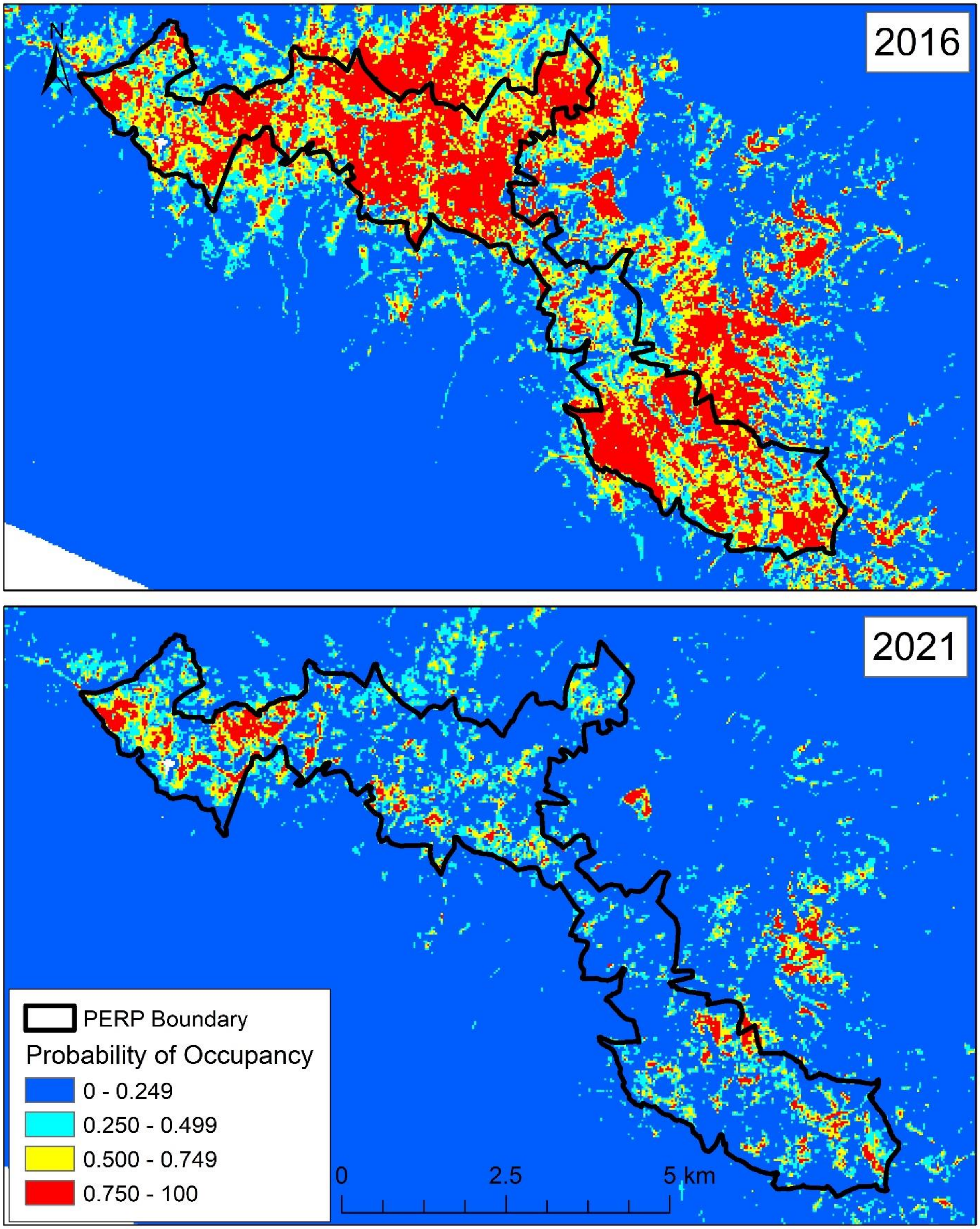

Figure 5: Probability of occupancy of Mount Graham red squirrels (*Tamiasciurus fremonti grahamensis*) in 2016 before a large-scale wildfire and again in 2021 four years following fire. The black boundary indicates the planned forest treatment zone associated with the Pinaleño Ecosystem Restoration Plan in southeastern, AZ, USA.

Conclusions

Consequences of wildfire are changing as drivers influencing wildfire behavior change (Johnstone et al. 2016). Wildfire can be beneficial in many ways, however, when fueled by a combination of drought, bark beetle damage, and invasive species, wildfire can facilitate entire shifts in forest composition and structure and compromise resilience (Peters 1990; Folke et al. 2004; Allen et al. 2010; Chmura et al. 2011). Our results demonstrate the need to monitor and assess the impacts of pre-fire forest treatments on post-fire forest composition, structure, and resilience. Overall, fuel treatments did have a positive impact on post-fire forest conditions, however, silviculture treatments did not and, in some cases, performed worse in comparison to control units. Fuel treatments were associated with increased CWD, increased herbaceous diversity, decreased probability of tree mortality, and increased forest resilience in comparison to control units. Silviculture treatments were also associated with increased CWD, increased herbaceous diversity, but were also associated with increased burn severity, increased soil temperatures, and did not differ from control units for tree mortality or forest resilience. Fuel treatments were associated with higher post-fire habitat suitability for MGRS in comparison to control units, whereas silviculture units performed worse than control units for retaining habitat post-fire. It is likely that effectiveness of silviculture treatments was poor because of high accumulation of woody debris remaining in the understory pre-fire. Some of the woody debris (such as slash piles and felled trees) was slated for removal while other debris was chipped and/or scattered as part of the planned prescription.

Implications for Management/Future Research Recommendations

Our results indicate that fuel treatments both improved forest resilience and helped conserve MGRS habitat through fire. We recommend continuing these treatments within and surrounding MGRS critical habitat to reduce the susceptibility of mature forests to severe wildfire, thereby threatening continued persistence of MGRS. We believe our results for silviculture treatments were confounded by slash piles and scattered woody debris from mastication and lop-and-scatter treatments immediately pre-fire. Additionally, mechanical thinning of the overstory coupled with higher burn severity resulted in detrimental loss of potential habitat for MGRS both pre- and post-fire. We do not recommend silviculture treatments as a method to maintain or improve MGRS habitat. If silviculture treatments are used, we recommend they be used outside of critical habitat and that slash and wood chips be immediately burned or largely removed from the site to reduce the susceptibility of these forests to high severity fire. Overall, it appeared that slash disposal treatment rather than treatment category (fuel or silviculture) per se was most predictive of post-fire forest condition, resilience, and probability of occupancy for MGRS.

To assess effectiveness of future treatments, we recommend maintaining long-term forest inventory plots to assess change in forest condition over time. We monumented all our plots with rebar at plot center so that individuals may return to those locations to reassess changes in forest composition and structure. We also recommend continuing annual assessments of MGRS habitat suitability using the logistic regression equation used in this report and in Hatten (2014). Additionally, we also recommend maintaining relationships with research teams to establish long-term studies that test the effect of slash depth and other forest treatment byproducts on fire behavior (Stephens & Moghaddas 2005; Clark et al. 2021). Knowing exactly what is present on the ground before a fire will be essential to promote learning and to adjust treatment protocols as necessary. It is possible that treatments which involve scattering slash in the understory may no longer be effective due to drying conditions that prevent slash from naturally decaying.

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Appendix B: List of Science Delivery Products

Deliverable Type (see proposal instructions)	**Description**	**Delivery Status**
Summary Guide	Summary of main conclusions pertinent to management partners with useful figures and tables	Complete
Adaptive Management Framework	An iterative learning-based structured decision model that will improve manager's ability to respond to future ecological uncertainty	In progress
Completed Project Overview	Two-page abbreviated report identifying key conclusions derived from the proposed work as well as management recommendations for continued improvement of silviculture treatments	In progress
Final Report	This report will summarize all data collected, analyses, and results which pertain to the scope of the proposed work	Complete
Publications (2)	1) Hefty, K.L., Koprowski, J.L. (2021). Effects of pre-fire forest and fuels treatment on forest composition, structure, and resilience. In prep for Forest Ecology and Management 2) Hefty, K.L., Koprowski, J.L. (2022). Post-fire trends in occupancy of an endangered species. In prep for Conservation Biology	In progress

Appendix C: Metadata

Metadata

We will use the Biological Data Profile standard associated with FGDC to document metadata for our spatial layers and field-collected metrics. We will use Metavist to document our metadata. Metadata will be made available as XML and ASCII. Data will additionally be uploaded to the JFSP online database and the USDA FS Research Data Archive.

Data Repository

We will deposit all non-sensitive data in the USDA FS Research Data Archive.

Data Access

We will deposit all non-sensitive data in the USDA FS Research Data Archive once all data has been collected, processed, QA/QC'ed, and published within 2 years following publication of research. Data referring to specific locations of Mount Graham red squirrel middens collected as part of this project cannot be fully disclosed in a public data repository due to the endangered status of this species and as dictated under permits from the US Fish and Wildlife Service and Arizona Game and Fish Department, however, all data derived from analyses of these locations (i.e. occupancy analysis) will be made available in a public repository. Data will additionally be made available through peer-reviewed publications in an open-access format and links to these data will be made in within published articles.